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(54) **COMBUSTION SYSTEM INCLUDING ONE OR MORE FLAME ANCHORING ELECTRODES AND RELATED METHODS**

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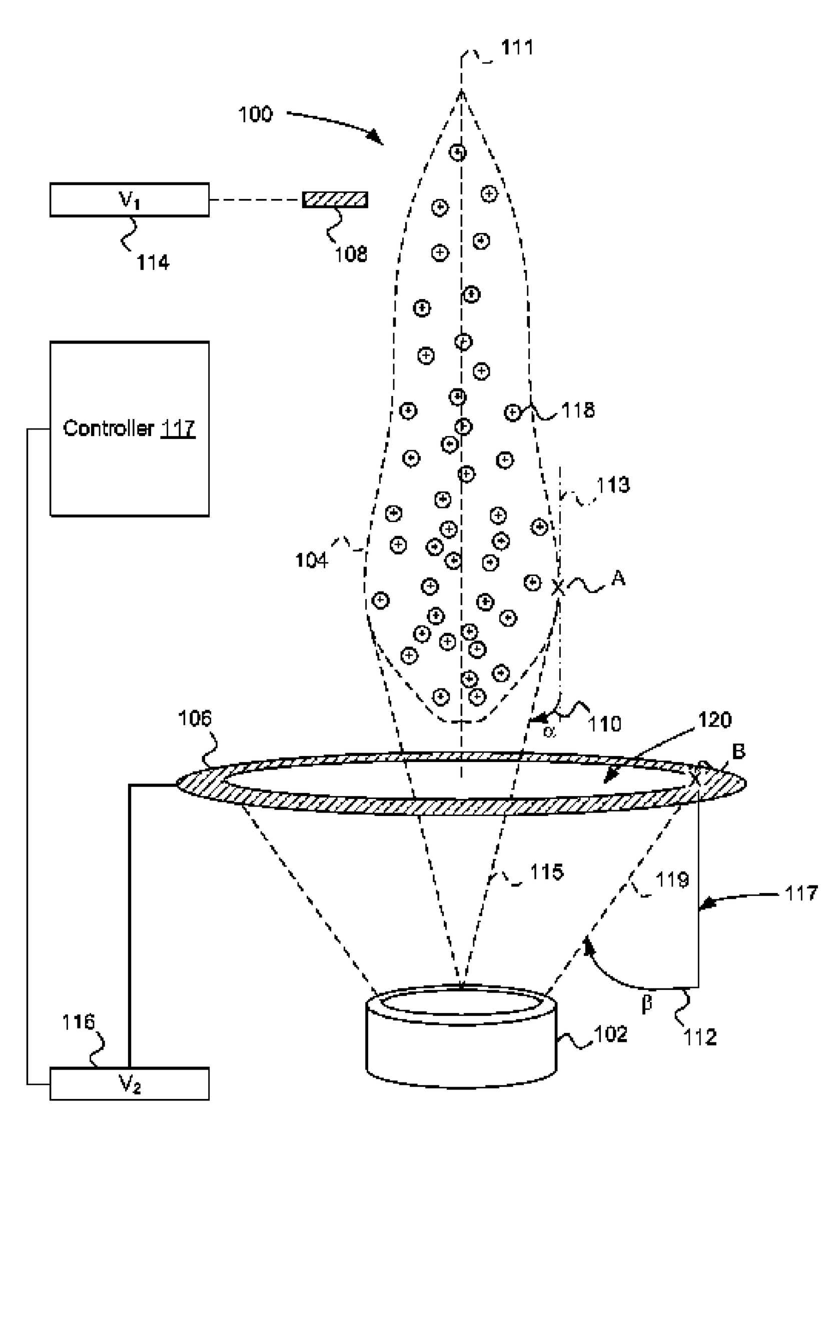
(57) **ABSTRACT**

In an embodiment, a combustion system includes a burner, at least one charging electrode, flame anchoring electrode(s), and at least one voltage power supply. The burner is configured to discharge fuel into a combustion volume in which the fuel and an oxidizer are ignited to generate a flame. The charging electrode is positioned proximate to the flame. The charging electrode provides charges to the flame to generate a charged flame. The flame anchoring electrode(s) are disposed adjacent to the burner and proximate to a base portion of the charged flame. The voltage power supply is electrically coupled to each of the flame anchoring electrode(s) and the charging electrode. The at least one voltage power supply applies one or more electrical potentials to each of the flame anchoring electrode(s) so that the charged flame is anchored at a predetermined location.

29 Claims, 3 Drawing Sheets



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See application file for complete search history.

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FIG. 1

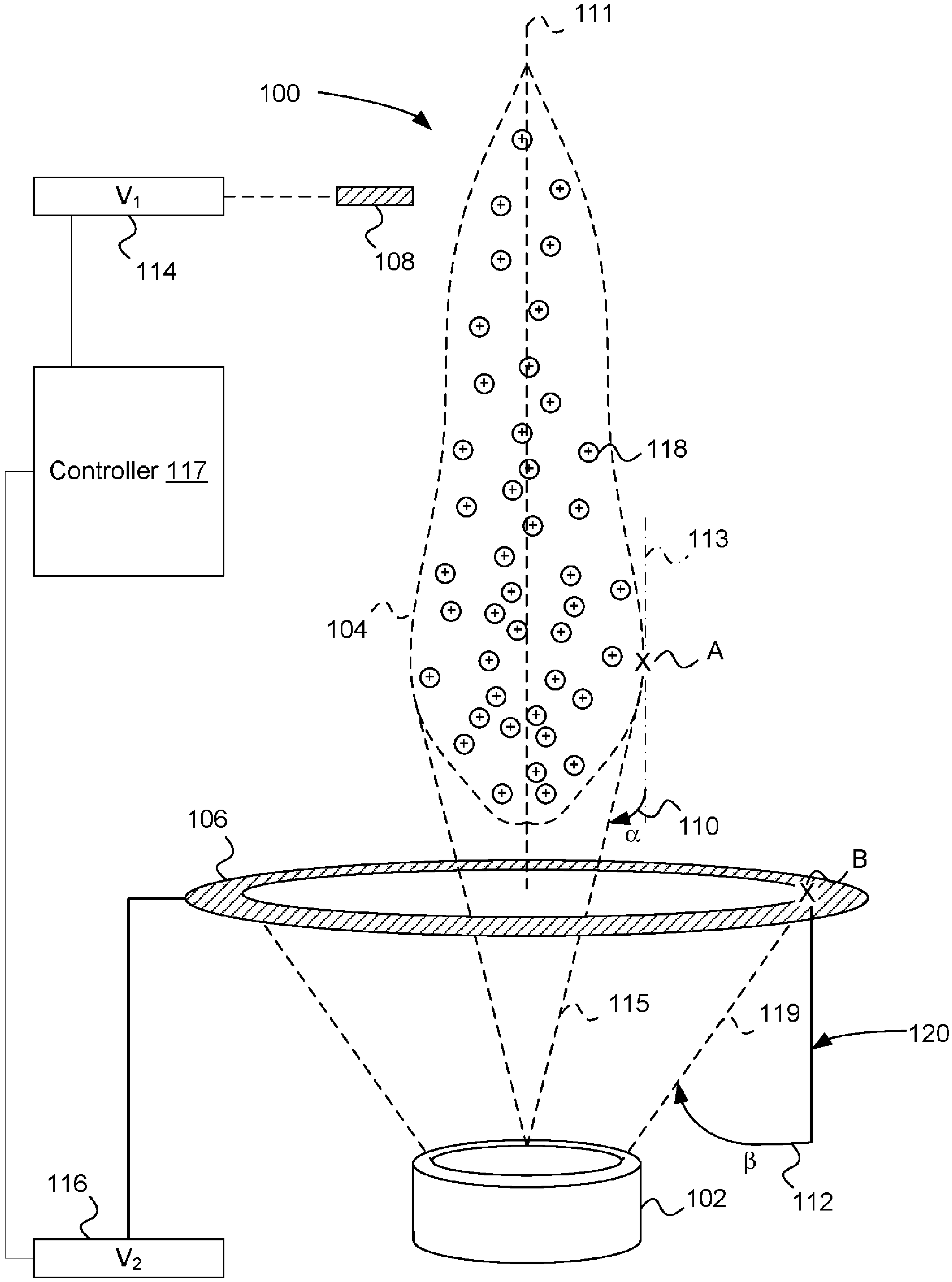

111
100
V1
108
114
Controller 117
118
113
104
A
106
110
α
B
115
119
120
β
112
116
102
V2

FIG. 2

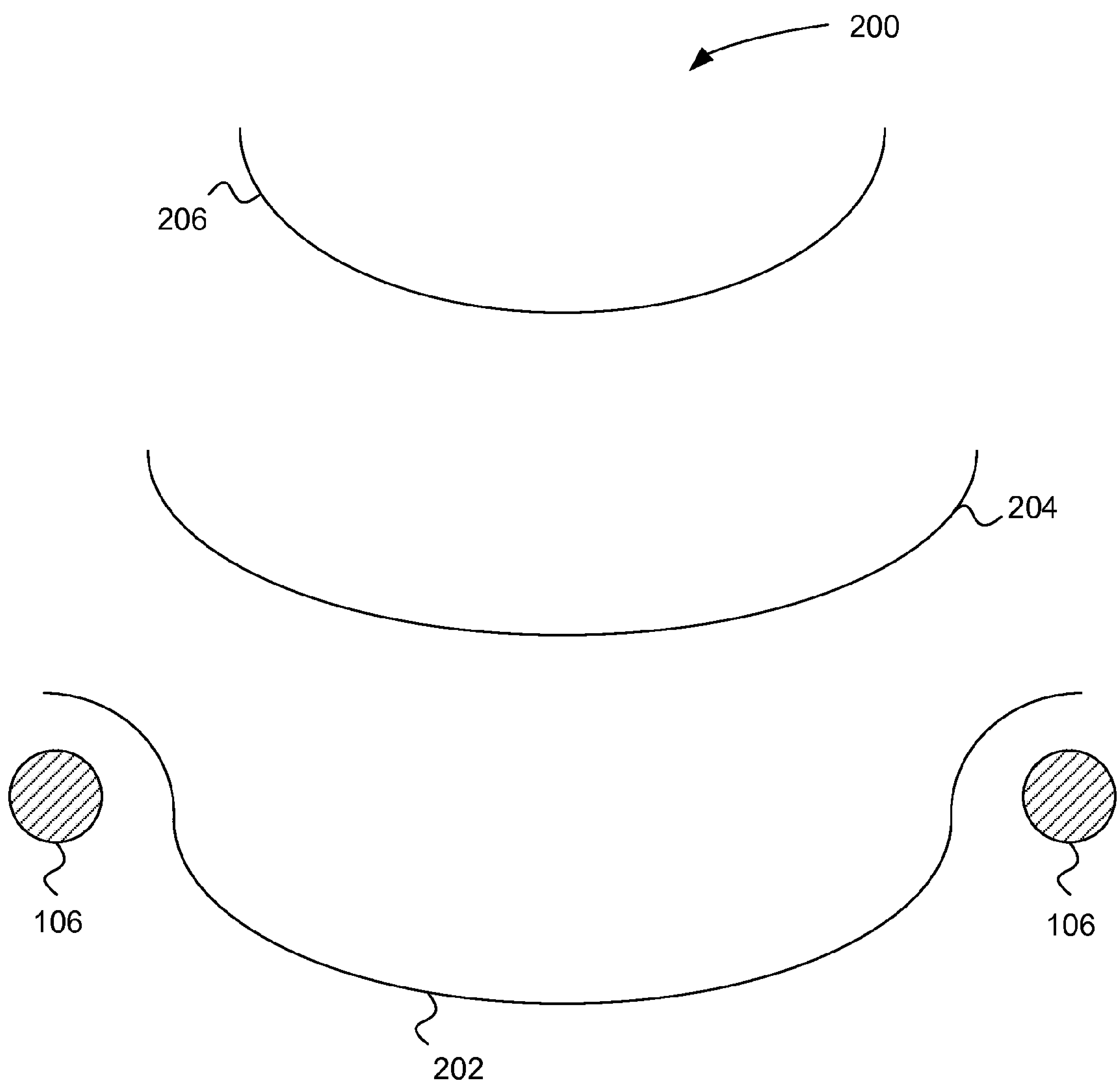
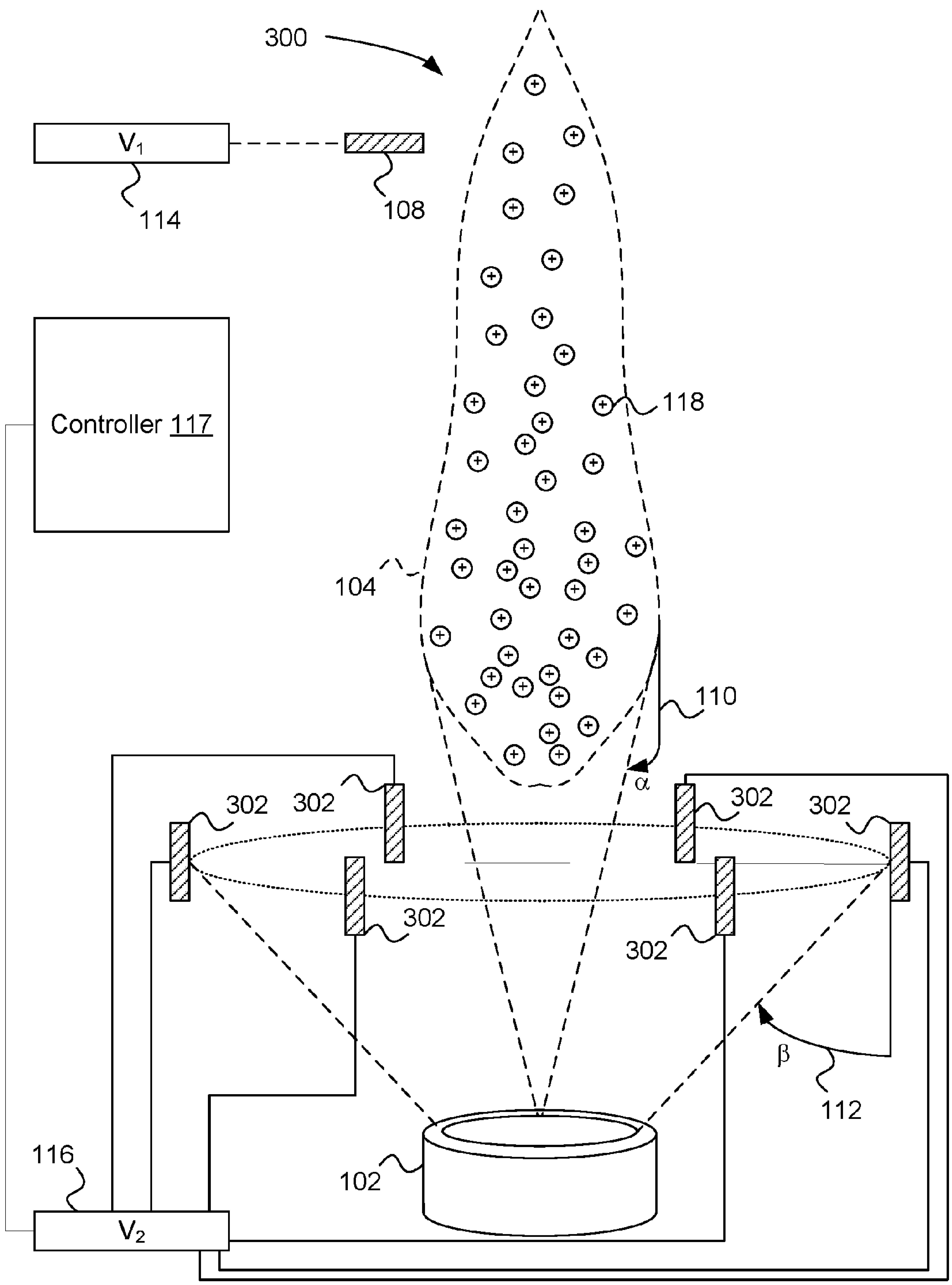


FIG. 3



300
V_1
114
108
118
Controller 117
104
110
α
302
302
302
302
302
302
302
302
β
112
116
102
V_2

COMBUSTION SYSTEM INCLUDING ONE OR MORE FLAME ANCHORING ELECTRODES AND RELATED METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 61/772,423 filed on 4 Mar. 2013; which, to the extent not inconsistent with the disclosure herein, is incorporated by reference.

BACKGROUND

Electric-field-based combustion control systems use electric fields to manipulate the movement of electrically charged molecules (e.g., ions) that are a natural production of the combustion process. The controlled electric field creates electrostatic forces (e.g., Coulombic body forces) within a gas cloud created by the combustion process that can be manipulated to control flame shape, heat transfer, and other flame characteristics. At the same time, the controlled electric field can help influence combustion chemistry to suppress formation of pollutants at the flame source.

Generally, these combustion control systems involve the use of one or two or more tubular, planar, or post-type electrodes fabricated from macroscopic metallic sheets, pipes, or rods. However, the ability of such electrodes to control electric fields can be limited and lacking in precision. Moreover, such electrodes can be susceptible to heat-induced failure and/or significant wear.

Therefore, developers and users of combustion control systems continue to seek improved designs for combustion control systems.

SUMMARY

Embodiments disclosed herein relate to combustion systems configured to control a position of a flame within a combustion volume of a combustion system. In an embodiment, a combustion system includes a burner, at least one charging electrode, one or more flame anchoring electrodes, and at least one voltage power supply. The burner is configured to discharge fuel into a combustion volume in which the fuel and an oxidizer are ignited to generate a flame. The at least one charging electrode is positioned proximate to the flame and, in some embodiments, the at least one charging electrode does not make contact with the flame. The at least one charging electrode is configured to charge the flame to generate a charged flame. The one or more flame anchoring electrodes are disposed adjacent to the burner and proximate to a base portion of the charged flame and, in some embodiments, the one or more flame anchoring electrodes are positioned so that they do not make contact with the charged flame. The at least one voltage power supply is electrically coupled to each of the one or more flame anchoring electrodes and the at least one charging electrode. The at least one voltage power supply is configured to apply one or more electrical potentials to each of the one or more flame anchoring electrodes so that the charged flame may be stably positioned at a predetermined location.

In an embodiment, a method for positioning a flame within a combustion volume is disclosed. A flow including fuel is discharged from a burner into a combustion volume. The fuel and an oxidizer is ignited to generate a flame. The flame is charged to generate a charged flame. An electrical potential is applied to each of one or more flame anchoring electrodes positioned proximate to a base of the charged flame to stably positioning the charged flame at a predetermined location.

Features from any of the disclosed embodiments may be used in combination with one another, without limitation. In addition, other features and advantages of the present disclosure will become apparent to those of ordinary skill in the art through consideration of the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagrammatic view of an embodiment of a combustion system including a charging electrode and a flame anchoring electrode for controlling an anchoring position of a flame.

FIG. **2** is a schematic diagrammatic view illustrating a position of a flame in relation to a potential difference applied to flame, according to an embodiment.

FIG. **3** is a schematic diagrammatic view of an embodiment of combustion system including a charging electrode and a group of flame anchoring electrodes for controlling an anchoring position of a flame.

DETAILED DESCRIPTION

Embodiments disclosed herein relate to combustion systems configured to control a position of a flame within a combustion volume of a combustion system. The disclosed combustion systems may be used to control a position of a flame away from walls, tubes, pipes, and other sensitive components within a combustion system.

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, which are not to scale or to proportion, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings and claims, are not meant to be limiting. Other embodiments may be used and/or and other changes may be made without departing from the spirit or scope of the present disclosure.

Controlling a flame anchoring position in certain areas within a combustion system may provide improve one or more of air/fuel mixing, flame stability, reduction of pollutants (e.g., NO_R, and CO), longer life, or higher reliability of equipment, among others. Furthermore, controlling the flame anchoring position within the combustion system may be important in ethylene crackers, steam methane reformers and other heaters, reactors and furnaces used in oil and chemical processing applications. In these systems, the position of the flame may need to be carefully controlled near pipes and other sensitive components to avoid excessive temperatures that may produce accumulation/penetration of species, such as carbon on the walls of internal structures (e.g., pipes/tubes), which may lead to the subsequent failure of these structures.

According to one or more embodiments, combustion systems may use one or more voltage power supplies, and one or more flame anchoring electrodes for repelling or attracting a charged flame in order to anchor the flame to a certain position within the combustion system. The charged flame may be generated by at least one charging electrode separate from the one or more flame anchoring electrodes, which is disposed near a flame within the combustion system and configured to inject charges into the flame to impart a net charge/polarity to the flame. In some embodiments, the life span of each of the one or more flame anchoring electrodes and at least one charging electrode may be extended because no contact with the flame is established or required. In addition, the flame anchoring electrode may exhibit a toric shape, such as an annulus shape having a diameter larger than an average diameter of the flame. Such a relationship may enhance flame anchoring by avoiding electrical isolation effect provided by the air gap between the flame and the flame anchoring electrode.

FIG. **1** illustrates an embodiment of a combustion system **100** that includes include a nozzle **102** or other type of burner configured to output fuel that ignites with an oxidizer (e.g., air or other oxidizer) to generate a flame **104** in a combustion volume; one or more annular flame anchoring electrode(s) **106** configured to anchor the flame **104** via electrodynamic interaction with the flame **104**; and at least one charging electrode **108** configured to emit charges into the flame **104** to impart a net charge/polarity to the flame **104**. In some embodiments, the fuel may be premixed with the oxidizer, and the fuel and oxidizer may exit the nozzle **102** together therewith.

The flame anchoring electrode(s) **106** and the at least one charging electrode **108** may each be made from a suitable electrically conductive material, such as a metal or an alloy. Anchoring of the flame **104** may include attachment of the flame **104** to and/or positioning of the flame **104** in a certain area at or near the flame anchoring electrode(s) **106** in such a way that the flame **104** may stay in contact with or be confined to areas proximate to that the flame anchoring electrode(s) **106**. In some embodiments, the flame anchoring electrode(s) **106** and at least one charging electrode **108** may be positioned and configured so that they are not in contact with the flame **104** during operation. According to various other embodiments, anchoring of the flame **104** may be suitable for use with a large variety of fuels in different combustion applications, such as gas, liquid, and solid fuels, which may be injected through a burner, an injector or the nozzle **102**.

The flame anchoring electrode(s) **106** may exhibit a number of different shapes, quantities, and sizes according to desired characteristics of the flame **104**. In the illustrated embodiment, the flame anchoring electrode(s) **106** is a single, complete annular flame anchoring electrode. However, in other embodiments, the flame anchoring electrode(s) **106** may exhibit different arrangements around the flame **104**, such as a generally square shape, a generally triangular shape, or other suitable partial or complete toric body.

In the illustrated embodiment, the flame anchoring electrode(s) **106** and at least one charging electrode **108** may be biased by separate voltage power sources (**114** and **116**) by application of an AC or a DC voltage potential, which is operably coupled to a controller **117** that directs operation of the voltage power sources **114** and **116**. For example, one or more of the voltage, charge, or electric fields may be applied with a plurality of waveforms and voltages/current intensities, according to a specific, desired position of the flame **104**. However, in other embodiments, a single voltage power source may be employed. The controller **117** may be a programmable controller and/or may be controlled by any computing device such as a desktop computer, etc.

In operation, the flame **104** may be positively charged by emission of charges from the at least one charging electrode **108**, resulting in the charged flame **104** carrying a majority of positively charged species **118**. The flame **104** may alternatively be negatively charged, resulting from the charged flame **104** carrying a majority of negatively charged species. Additionally or alternatively, the charged flame **104** may carry a time-varying charge polarity resulting from alternately carrying a majority of positively charged species **118**, then negatively charged species. For ease of understanding, the charge of the charged flame **104** will be considered to be positive in the following description. Moreover, it is currently believed by the inventors and experiments by the inventors have shown positive flame charge to be somewhat more effective for electrical flame holding that is negative flame charge.

The charge/polarity of the flame **104** may be generated by the at least one charging electrode **108** including a charge-ejecting electrode (e.g., a corona electrode that may be configured as a nail, a portion of a saw tooth blade, or other suitable charge-ejecting structure) that ejects charges into the flame **104**, by an immersed or partially immersed charge depletion electrode, by an ion generator removed from proximity with the flame, by an inertial electrode, by other suitable structures, or combinations thereof. The at least one charging electrode **108** may be energized with the voltage power source **114** configured to apply a first voltage potential V_1, which may hold a constant positive charge or positive voltage potential. Alternatively, as described above, another constant or variable charge polarity may be selected by corresponding selection of an appropriate voltage power source.

The flame anchoring electrode(s) **106** may be located in proximity to the flame **104**. For example, the flame **104** may have a first diameter and form an angle α **110** of about 3 to about 10 degrees (e.g., 7.5 degrees) in relation with a vertical reference axis **111**. The flame anchoring electrode(s) **106** may have a second diameter that is larger than the first diameter of the flame **104**. The second diameter may correspond to the projection of angle β **112**, which may be greater than angle α **110** ($\beta>\alpha$). This relationship between angles **110**, **112** is intended to provide clearance between the flame **104** and flame anchoring electrode(s) **106**.

In practice, because the flame anchoring electrode **106** may be positioned coaxially with and at an arbitrary distance away from a top surface of the nozzle **102** and the inside diameter of the flame anchoring electrode **106** is larger than the diameter of the flame **104**, the relationship between these two diameters may be expressed in terms of angles formed between each of several features common to the combustion system **100**. In particular, the diameter of the flame **104** may be expressed in terms of the first angle α **110** formed between a line **113** drawn substantially parallel to the vertical axis **111** through the flame **104** and tangent to a widest part of the flame **104** at point A and a line **115** extending from an inside edge of the nozzle **102** to the same point A. Likewise, the inside diameter of the flame anchoring electrode(s) **106** may be expressed in terms of the second angle β **112** formed between a line **120** drawn substantially parallel to the vertical axis **111** and tangent with a point B along an inside edge of flame anchoring electrode(s) **106** and a line **119** extending from an inside edge of the nozzle **102** to the same point B. In some embodiments, it is desirable that diameter of the flame anchoring electrode(s) **106** be greater than the diameter of the flame **104** and, therefore, $\beta>\alpha$.

According to Coulomb's Law of charge repulsion, if the flame **104** needs to be anchored to a certain position, such as far away from tubes or pipes of heat exchangers, then the flame anchoring electrode(s) **106** may be charged by a second voltage power supply **116** at the second voltage potential V_2 that may exhibit a reverse/opposite polarity with respect to the charged flame **104**. This may result in the charged flame **104** being pushed down and anchored to the flame anchoring electrode(s) **106** and in proximity to, but without making contact with the flame anchoring electrode(s) **106**. Conversely, if the charged flame **104** needs to be lifted up and anchored above the flame anchoring electrode(s) **106**, then the flame anchoring electrode(s) **106** may be charged with the same polarity as the flame **104**. The flame anchoring electrode(s) **106** may also be placed within different regions or objects and may be positively or negatively charged to repel or attract the charged flame **104**. Furthermore, the at least one charging electrode **108** may be located in different regions of the combustion system **100** including within a burner, an injector, or the nozzle **102**.

FIG. **2** illustrates examples of different flame anchoring positions **200**, with respect to the flame anchoring electrode(s) **106**, which is depicted in cross-sectional view. The flame anchoring positions **200** may depend on the electrical potential difference between the charged flame **104** and flame anchoring electrode(s) **106**, where a higher electrical potential difference may result in a stronger and nearer anchoring of the flame **104** to flame anchoring electrode(s) **106**. For example, the charged flame **104** may be located at position **202** when a negative voltage of about 20 Kilo-volts (KV) may be applied to the flame anchoring electrode(s) **106**, where position **202** may be slightly below an inner diameter of flame anchoring electrode(s) **106**. Correspondingly, position **204** above the position **202** may be achieved by the application of a negative voltage of about 1 KV to the flame anchoring electrode(s) **106**. Similarly, position **206** above the position **204** may be achieved when no voltage is applied to the flame anchoring electrode(s) **106**.

Furthermore, the voltage potential required for anchoring the charged flame **104** may vary according to a flow rate of fuel and oxidizers and various other conditions during combustion such as, for instance, fuel constituents, fuel, pressure, temperature, and the like. In addition, if the charged flame **104** is required to be anchored in a higher or lower position, then retrofitting (not shown) may be easily provided for by simply re-locating flame anchoring electrode(s) **106** above or below the nozzle **102**.

FIG. **3** illustrates an embodiment of a combustion system **300** that employs the principles illustrated in FIGS. **1** and **2** and described in the foregoing detailed description. The combustion system **300** includes nozzle **102** configured to output fuel that ignites to form flame **104**; at least one charging electrode **108**; and a plurality of flame anchoring electrodes **302** spaced from each other and disposed peripherally about the flame **104** during operation. The plurality of flame anchoring electrodes **302** are configured to anchor the flame **104** via electrodynamic interaction with the flame **104**. For example, the plurality of flame anchoring electrodes **302** may be circumferentially spaced from each other or laterally spaced from each other another manner. The plurality of flame anchoring electrodes **302** and at least one charging electrode **108** may be biased by separate voltage power sources **116** and **114** configured to apply an AC or a DC voltage potential V_2 and an AC or a DC voltage potential V_I, respectively thereto. Furthermore, in some embodiments, the plurality of flame anchoring electrodes **302** and at least one charging electrode **108** may be positioned and configured so that they are not in contact with the flame **104**.

The plurality of flame anchoring electrodes **302** may be located in proximity to the flame **104**, where the flame **104** edge may form an angle α **110** of, for example, about 7.5 degrees with respect to a vertical axis, as discussed above when describing the embodiment illustrated in FIG. **1**. Moreover, the plurality of flame anchoring electrodes **302** may be circumferentially spaced from each and positioned along a diameter corresponding to the projection of angle β

112, (again as discussed above with regard to FIG. **1**) which may be greater than angle α **110** (β>α), such that the diameter along which the plurality of flame anchoring electrodes **302** are positioned may be greater than a diameter of flame **104**. This relationship between the angles **110** and **112** may provide clearance between flame **104** and segmented electrodes **302**.

In some embodiments, each of the plurality of flame anchoring **302** may be biased to the same potential to attract or repel the charged flame **104**. In another embodiment, different or separate voltage potentials may be applied to each of the plurality of flame anchoring electrodes **302** from individual power sources, such that individual voltage potentials may allow different flame anchoring positions **200** and other effects to the plurality of flame anchoring electrodes **302** flame **104**. For example, one or more of the plurality of flame anchoring electrodes **302** may be charged to anchor the plurality of flame anchoring electrodes **302** flame **104**, while the rest of the plurality of flame anchoring electrodes **302** may remain without any charge. In another embodiment, the plurality of flame anchoring electrodes **302** may be charged sequentially as required by the application.

In an embodiment, any of the methods described herein may be performed by a computer system having at least one processor configured to execute computer-executable instructions and process operational data. For example, the processor may be operably coupled to a memory storing an application including computer-executable instructions and operational data constituting a computer program to perform any of the methods disclosed herein and incorporated in a controller such as the controller **117** of FIGS. **1** and **3**. For example, the processor may be operably coupled to a memory storing an application including computer executable instructions and operational data constituting a program to control combustion characteristics of a flame using combustion control systems **100** and/or **300**.

The memory may be embodied as a computer readable medium, such as a random access memory ("RAM"), a hard disk drive, a static storage medium such as a compact disk, DVD, or other non-transitory storage medium. The memory may further store property data describing properties of the flame and/or electrode assemblies determined as described hereinabove. The computer system may further include a display coupled to the processor. The processor may be operable to display the images of the flame and other graphical illustrations of the characteristics of the flame on the display.

While various aspects and embodiments have been disclosed, other aspects and embodiments may be contemplated. The various aspects and embodiments disclosed here are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

The invention claimed is:

1. A combustion system, comprising:

a burner configured to discharge fuel into a combustion volume in which the fuel and an oxidizer are ignited to generate a flame;

at least one charging electrode positioned proximate to the flame, the at least one charging electrode configured to emit charges into the flame to generate a charged flame exhibiting a net charge and/or polarity;

one or more flame anchoring electrodes disposed adjacent to the burner and proximate to a base portion of the charged flame; and

at least one first voltage power supply electrically coupled to the at least one charging electrode, wherein the at least one charging electrode provides charges to the flame responsive to being biased by the first voltage power supply; and

at least one second voltage power supply electrically coupled to the one or more flame anchoring electrodes, the at least one second voltage power supply configured to apply one or more electrical potentials to each of the one or more flame anchoring electrodes so that a base of the charged flame is stably positioned at a predetermined location, wherein the position of the base of the charged flame is spaced from the burner at the predetermined location.

2. The combustion system of claim **1** wherein the one or more flame anchoring electrodes are disposed peripherally about the burner.

3. The combustion system of claim **1** wherein the one or more flame anchoring electrodes includes a single flame anchoring electrode configured as a toric body.

4. The combustion system of claim **1** wherein the one or more flame anchoring electrodes includes a plurality of flame anchoring electrodes that are laterally spaced from each other.

5. The combustion system of claim **1** wherein the one or more flame anchoring electrodes includes a plurality of flame anchoring electrodes that are circumferentially spaced from each other.

6. The combustion system of claim **1** wherein the burner includes a nozzle configured to discharge the fuel.

7. The combustion system of claim **1** wherein the burner is configured to discharge the oxidizer mixed with the fuel.

8. The combustion system of claim **1** wherein the at least one second voltage power supply is configured to bias the one or more flame anchoring electrodes to exhibit a polarity opposite to that of the charged flame.

9. The combustion system of claim **1** wherein the at least one second voltage power supply is configured to bias the one or more flame anchoring electrodes to exhibit a polarity the same as that of the charged flame.

10. The combustion system of claim **1** wherein the one or more flame anchoring electrodes includes a plurality of flame anchoring electrodes, and wherein the at least one second voltage power supply is configured to bias each of the plurality of flame anchoring electrodes at different respective potentials.

11. The combustion system of claim **1** wherein the one or more flame anchoring electrodes includes a plurality of flame anchoring electrodes, and wherein the at least one second voltage power supply is configured to bias each of the plurality of flame anchoring electrodes at substantially the same potential.

12. The combustion system of claim **1** wherein the at least one charging electrode includes a corona electrode configured to emit charges into the flame.

13. The combustion system of claim **12**, wherein the corona electrode includes at least one of a nail or a portion of a saw tooth blade.

14. The combustion system of claim **1** wherein the at least one charging electrode and the one or more flame anchoring electrodes do not contact the charged flame during operation.

15. The combustion system of claim **1**, wherein the at least one charging electrode includes at least one of an at least partially immersed charge depletion electrode, an ion generator, or an inertial electrode.

16. The combustion system of claim **1**, wherein the at least one second voltage power supply is configured to apply the one or more electrical potentials to each of the one or more flame anchoring electrodes so that a base of the charged flame changes position relative to the burner, wherein the position of the base of the charged flame is spaced from the burner.

17. A method for positioning a flame within a combustion volume, comprising:

discharging a flow including fuel from a burner into a combustion volume;

igniting the fuel and an oxidizer to generate a flame;

emitting charges from at least one charging electrode into the flame to generate a charged flame exhibiting a net charge and/or polarity; and

applying an electrical potential to each of one or more flame anchoring electrodes positioned proximate to a base of the charged flame to stably position the base of the charged flame at a predetermined flame anchoring position that is spaced from the burner, wherein the flame anchoring position is different than the location of the charged flame when no electrical potential is applied to each of the one or more flame anchoring electrodes.

18. The method of claim **17** wherein the one or more flame anchoring electrodes are disposed peripherally about the burner.

19. The method of claim **17** wherein the one or more flame anchoring electrodes includes a single flame anchoring electrode.

20. The method of claim **17** wherein the one or more flame anchoring electrodes includes a plurality of flame anchoring electrodes that are laterally spaced from each other.

21. The method of claim **17** wherein the one or more flame anchoring electrodes includes a plurality of flame anchoring electrodes that are circumferentially spaced from each other.

22. The method of claim **17** wherein discharging a flow stream including fuel from a burner into a combustion volume includes discharging a mixture of the fuel and the oxidizer from the burner.

23. The method of claim **17** wherein applying an electrical potential to each of one or more flame anchoring electrodes positioned proximate to a base of the charged flame to stably positioning the base of the charged flame at a predetermined location includes biasing the one or more flame anchoring electrodes to exhibit a polarity opposite to that of the charged flame so that the base of the charged flame is attracted to the one or more flame anchoring electrodes.

24. The method of claim **17** wherein applying an electrical potential to each of one or more flame anchoring electrodes positioned proximate to a base of the charged flame to stably positioning the base of the charged flame at a predetermined location includes biasing the one or more flame anchoring electrodes to exhibit a polarity that is substantially the same to that of the charged flame so that the base of the charged flame is repelled from the one or more flame anchoring electrodes.

25. The method of claim **17** wherein applying an electrical potential to each of one or more flame anchoring electrodes positioned proximate to a base of the charged flame to stably positioning the base of the charged flame at a predetermined location includes biasing each of the one or more flame anchoring electrodes at different respective potentials.

26. The method of claim 17 wherein applying an electrical potential to each of one or more flame anchoring electrodes positioned proximate to a base of the charged flame to stably positioning the base of the charged flame at a predetermined location includes biasing each of the one or more flame anchoring electrodes at substantially the same potential.

27. The method of claim 17, further comprising selecting a voltage to be applied to each of the one or more anchoring electrodes to attract the base of the charged flame to the predetermined flame anchoring position, wherein the predetermined flame anchoring position is nearer to the one or more flame anchoring electrodes than if no voltage is applied to each of the one or more anchoring electrodes.

28. The method of claim 17, wherein applying an electrical potential to each of one or more flame anchoring electrodes to a base of the charged flame to stably position the charged flame at a predetermined flame anchoring position includes applying an electrical potential to each of the one or more flame anchoring electrodes to stably position the charged flame away from one or more of the at least one charging electrode, the one or more flame anchoring electrodes, walls, tubes, or pipes.

29. A combustion system, comprising:

a burner including a nozzle configured to discharge a mixture comprising fuel and air into a combustion volume in which mixture is ignited to generate a flame;

at least one corona electrode positioned proximate to the flame without making contact with the flame, the at least one corona electrode configured to emit charges into the flame;

a plurality of flame anchoring electrodes spaced from each other and disposed proximate to a base portion of the charged flame without making contact with the charged flame;

at least one voltage power supply electrically coupled to each of the plurality of flame anchoring electrodes and the at least one corona electrode, the at least one voltage power supply configured to apply one or more electrical potentials to each of the plurality flame anchoring electrodes so that a base of the charged flame is attracted to the plurality of flame anchoring electrodes, wherein the base of the charged flame is spaced from the burner.

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